Nearshore Processes Research

A Status Report from the Nearshore Processes Workshop,
St. Petersburg, FL, April 24–26, 1989

Executive Summary

0.1 Background

Coastal regions are disproportionately important for commerce, recreation and the defense of our country. Yet our knowledge of the processes that govern the nearshore region is inadequate to deal with present and future coastal problems. For example, erosion presently occurs over 70% of the U.S. coast with rates likely to accelerate owing to the rise of sea level associated with global warming.

From April 24 - 26th, 1989, a group of 60 scientists specializing in nearshore processes met in St. Petersburg, Florida, with the objective of assessing the current state of the science, determining the methodologies that have been most successful in the past, and identifying important directions of research emphasis for the future.

0.2 Present level of understanding

As ocean waves propagate into shallow nearshore waters, they undergo a rich set of nonlinear interactions that spread energy to both higher and lower frequencies in a way that depends on the topography of the beach. In addition, these fluid motions cause transport of the underlying sediment at the seabed, potentially leading to large changes in that topography. This complex interaction yields the ever-changing suite of beach morphologies that we are accustomed to.

Our knowledge of this system and ability to predict consequences of such changes as sea level rise are hindered by our poorly-developed understanding of certain key links in the chain of nearshore processes. An important function of the nearshore workshop was identification of those important areas for future research.

0.3 Recommendations for future research

It is clear that incident band processes will continue to form the foundation of nearshore research. However, five areas were further identified as being particularly important to the improvement of our understanding. Listed in order of increasing complexity, the focus areas are:

1. infragravity band dynamics
2. swash dynamics
3. the dynamics of wave breaking
4. bottom boundary layer processes
5. the dynamics of small-scale sediment processes

For the first two topics, studies of infragravity and swash dynamics, a moderate increase in effort will probably result in a significant improvement in our level of understanding. The latter three problems are more difficult and will need to be attacked in steps over an extended period. In particular, sediment dynamics is dauntingly complex, but must be addressed in order for us to develop predictive skills of the nearshore response to wave forcing.

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1.0 Motivation

The coastal region of the United States is of high economic, recreational and strategic value. More than 50% of the American population lives within 50 miles of the coastline, and many more visit the coast each year. Ports and harbors are crucial for the export of American agricultural and industrial products as well as for the import of foreign goods. In addition to being important, the coastal region is subject to many natural forces, often resulting in disastrous consequences. Although storms have the most dramatic impact on coastal property, everyday exposure to waves and currents can have slow cumulative effects which are equally important. The majority (70%) of the American coastline is currently experiencing some degree of erosion.

Current mitigation techniques are crude and costly although often effective, at least in the short term. In many cases protection consists of armoring the coast, with a significant loss of aesthetic, recreational and ecological value. Moreover, many of these measures will only be temporary, since the slow rise of sea level will steadily increase the stress on the protective system.

Despite the importance of the coastal region, we do not yet have an adequate knowledge base to implement economically feasible and environmentally acceptable solutions to this inevitable coastal erosion. In order to maintain and maximize the value of our coastal resources we must develop an improved understanding of the processes by which shorelines respond to waves and currents.

2.0 Nearshore Processes Workshop

A workshop to consider the present and future state of nearshore processes research was held in St. Petersburg, Florida from April 24th to 26th, 1989. Funding for the workshop was provided cooperatively by five federal agencies; the Army Corps of Engineers, the National Science Foundation, Office of Naval Research, Sea Grant, and the U.S. Geological Survey. Hosting arrangements were kindly made by the U.S. Geological Survey, St. Petersburg, FL. The meeting was attended by a diverse group of 60, which included researchers and managers from both universities and government laboratories and agencies (Appendix I).

This report summarizes the results of the workshop. Discussions started with presentations on progress made in nearshore research during the last twenty years and a summary of our current knowledge (as detailed in sections 3 and 4 of this report). The focus then shifted to the future with emphasis on identification of both research directions with the highest potential scientific and engineering payoff, and the major hurdles that may hinder progress. Five priority areas were identified for future research (section 5). Finally, an overview of the meeting is given (section 6).

3.0 Overview of Nearshore Processes

The major goal of nearshore research is to understand the interaction between waves and currents propagating over topography which is itself being slowly altered by the fluid motions.

The energy that drives fluid motions in the nearshore comes primarily from sea and swell waves (typical wave periods of 3-20 sec) generated by both local and remote winds. As these incident waves progress into shallow nearshore waters, energy is nonlinearly transferred to both lower frequency motions (e.g., mean flows and infragravity waves with periods of minutes) and higher frequency motions (e.g., harmonics of the incident waves and turbulence) (figure 1).

The basic physics of this process depends on the incident waves and the beach topography, and also on whether wave breaking is occurring. Therefore, nearshore dynamics are commonly broken into 'shoaling' and 'surf zone' regimes, seawards of and within the breaking wave zone, respectively. Many aspects of the evolution of waves propagating from deep water through the shoaling region can now be accurately predicted by numerical models with little or no empiricism. Within the surf zone, breaking incident waves transfer energy to higher frequency turbulent motions, and most of the incident wave energy is dissipated. The dynamics of wave breaking and dissipation in the surf zone are poorly understood theoretically, and relevant field measurements are scarce.

One of the obstacles to our understanding of beach behavior has been the vastly different scales of processes that occur over different beach topographies. On steep beaches, the breaking region can be narrow to non-existent. Evolution of the incident spectrum occurs over only a few wavelengths and may not be extensive. On very flat beaches, evolution occurs over many wavelengths. Incident waves can be strongly dissipated and the dominant energy in the inner surf zone may result from nonlinear transfer to lower frequency infragravity waves. It is apparent that comparisons of data from different beaches will require a normalization that includes descriptors of the beach profile.

While the wave dynamics strongly depend on the beach topography, the topography is itself a result of the overlying waves and currents. Over a short period, the bathymetry may be considered fixed. However, the slow adjustments due to sediment transport can become significant on a time scale of hours to days. Cumulative changes to the beach profile can be an O(1) effect that must eventually be understood if we are to have predictive capability for beach processes.

There are many similarities between nearshore processes and other areas of oceanography. On the other hand, many aspects of the nearshore problem are unique. Some of the interesting physics arises because:

- the water depth goes to 0 within the region of interest,
- the nearshore acts as a wave guide, similarly to the continental shelf or the earth's crust (to acoustic waves). Wave guide dynamics can be an important element of the behavior of the system,
- nonlinearities can be strong. If a is the wave amplitude, h the local depth and k the wavenumber, then since a and k increase as h decreases, normal measures of nonlinearity such as a/h and ak must become large near the shoreline,
- the physical scaling of the nearshore (for example, the width of the surf zone) is variable, usually being a function of the incident wave conditions. This complicates sampling with fixed instruments,
- the bottom boundary is erodible and changes in response to the waves themselves.

Fortunately, there are several simplifications relative to large scale oceanographic flows:

- Coriolis force may be neglected due to the relatively high frequencies of the problem,
- the water column is well mixed so that stratification can be neglected except in a thin layer of sediment suspension near the bottom.

The following section describes our current understanding for the dominant processes, including large and sub-grid scale fluid processes and sediment transport.

Nearshore Momentum Budget

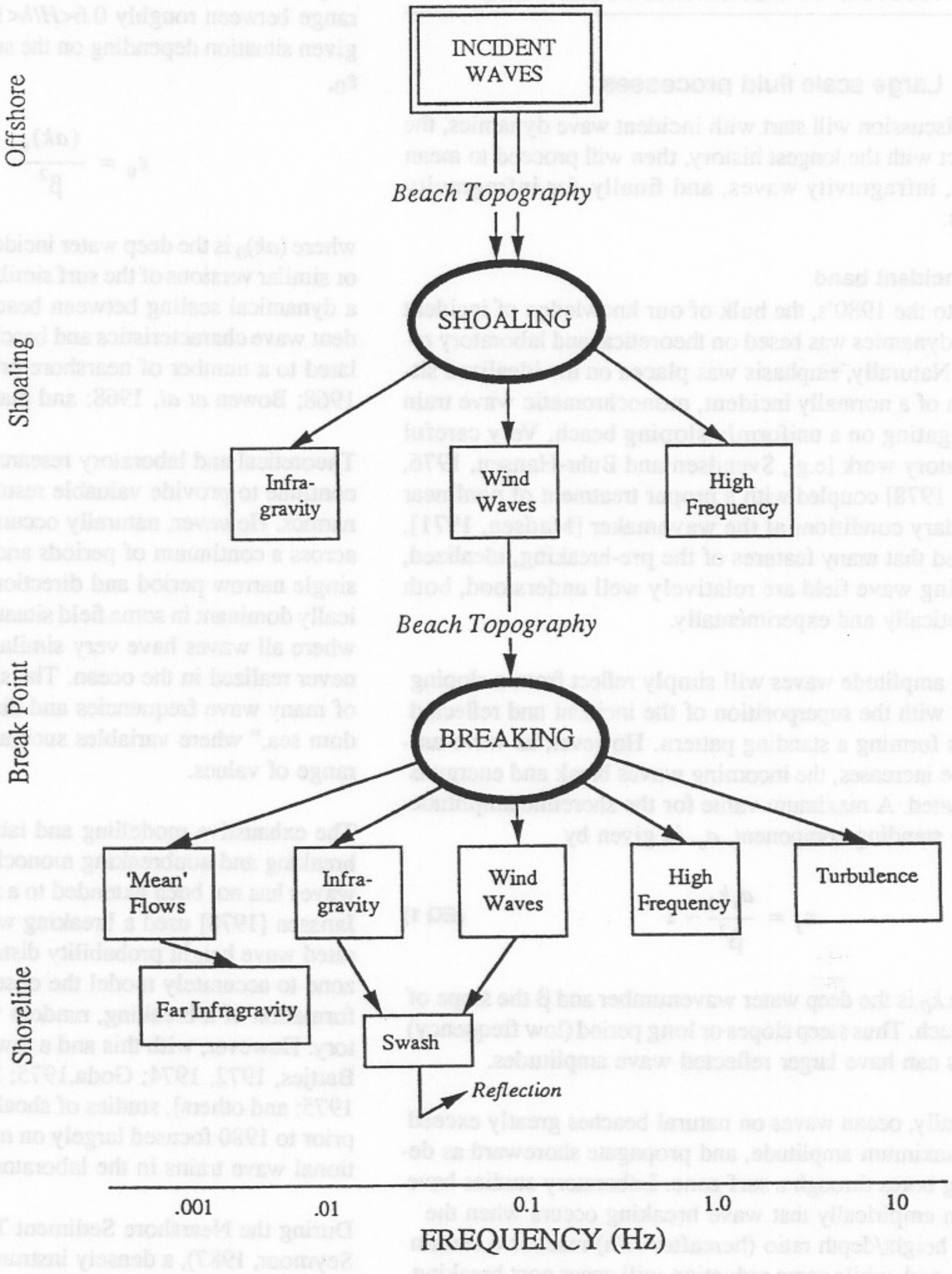

FIGURE 1. Schematic of important nearshore processes showing how the incident wave energy that drives the system evolves as the waves progress from offshore to the shoreline (top to bottom of the figure). Wave evolution is grouped into processes occurring seaward of the breakpoint (denoted "shoaling") and those within the surf zone (denoted "breaking"). In both cases, energy is spread to lower (left) and higher frequencies (right). The beach topography provides the bottom boundary condition for flow, so is important to wave processes. In turn, the waves move sediment, slowly changing the topography. Wind and tides may be important in some settings, but are not shown here.

4.0 Review of Dominant Processes

4.1 Large scale fluid processes

The discussion will start with incident wave dynamics, the subject with the longest history, then will proceed to mean flows, infragravity waves, and finally, far infragravity waves.

The incident band

Prior to the 1980's, the bulk of our knowledge of incident wave dynamics was based on theoretical and laboratory results. Naturally, emphasis was placed on the idealized situation of a normally incident, monochromatic wave train propagating on a uniformly sloping beach. Very careful laboratory work [e.g., Svendsen and Buhr-Hansen, 1976, 1977, 1978] coupled with a proper treatment of nonlinear boundary conditions at the wavemaker [Madsen, 1971], showed that many features of the pre-breaking, idealized, shoaling wave field are relatively well understood, both theoretically and experimentally.

Small amplitude waves will simply reflect from a sloping beach with the superposition of the incident and reflected waves forming a standing pattern. However, as wave amplitude increases, the incoming waves break and energy is dissipated. A maximum value for the shoreline amplitude of the standing component, a_s, is given by

$$\varepsilon_s = \frac{a_s k_0}{\beta^2} \sim 1 \qquad \text{(EQ 1)}$$

where k_0 is the deep water wavenumber and β the slope of the beach. Thus steep slopes or long period (low frequency) waves can have larger reflected wave amplitudes.

Typically, ocean waves on natural beaches greatly exceed this maximum amplitude, and propagate shoreward as decaying bores through a surf zone. Laboratory studies have shown empirically that wave breaking occurs when the wave height/depth ratio (hereafter H/h) reaches a certain value, and, while some reduction will occur post breaking, this ratio remains more or less constant during bore propagation and decay on a plane beach (the wave field is said to be saturated). The value of H/h is a critical parameter in many nearshore models including those for wave set-up (a super-elevation of the mean water level at the shoreline) and the generation of steady longshore currents. Laboratory results for monochromatic waves typically span a range between roughly $0.6<H/h<1.2$, with the value in a given situation depending on the surf similarity parameter, ε_0,

$$\varepsilon_0 = \frac{(ak)_0}{\beta^2} \qquad \text{(EQ 2)}$$

where $(ak)_0$ is the deep water incident wave steepness. This or similar versions of the surf similarity parameter provides a dynamical scaling between beaches with different incident wave characteristics and beach slopes and has been related to a number of nearshore processes [e.g., Galvin, 1968; Bowen *et al*, 1968; and many others].

Theoretical and laboratory research on regular waves will continue to provide valuable results on incident band dynamics. However, naturally occurring waves have energy across a continuum of periods and directions. Although a single narrow period and direction range may be energetically dominant in some field situations, the laboratory case where all waves have very similar heights and shapes is never realized in the ocean. The simultaneous occurrence of many wave frequencies and directions leads to a "random sea," where variables such as wave height have a range of values.

The exhaustive modelling and laboratory studies of both breaking and nonbreaking monochromatic, unidirectional waves has not been extended to a random sea. Battjes and Janssen [1978] used a breaking wave model that incorporated wave height probability distributions within the surf zone to accurately model the observed wave height transformation of a breaking, random wave field in the laboratory. However, with this and a few other exceptions, [e.g., Battjes, 1972, 1974; Goda,1975; Huntley and Bowen, 1975; and others], studies of shoaling and breaking waves prior to 1980 focused largely on monochromatic, unidirectional wave trains in the laboratory.

During the Nearshore Sediment Transport Study (NSTS; Seymour, 1987), a densely instrumented cross-shore array of current meters, pressure sensors and wave staffs allowed field testing of linear and nonlinear shoaling and breaking processes in the incident wave frequency band. As a first step, Guza and Thornton [1980] compared measured spectra from wave staffs and pressure sensors with those inferred by linear theory from current meter measurements (figure 2). Except in the immediate vicinity of the wave crest, the linear relationships at a point were surprisingly accurate (errors of 20% or less) throughout the breaking region, comparable to the agreement found outside the surf zone by earlier workers. In addition, the total variance throughout the shoaling region was predictable using linear shoaling from deep water, although the evolution of spectral structure was not well modelled.

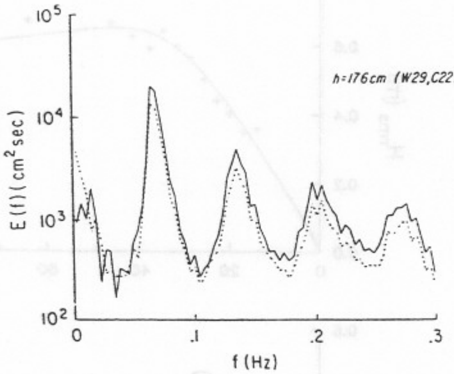

FIGURE 2. Spectra of sea surface elevation from a surface piercing staff (solid) and calculated from horizontal currents (dashed). Higher frequency peaks are harmonics of the 0.07 Hz primary (from Guza and Thornton, 1980).

Near the breaking region, surface gravity waves become distinctly nonsinusoidal, developing a peaked crest and pitching forward in a sawtooth form. The spectral signature of this wave shape is a series of harmonics (figure 2) with non-random phase relations (the fundamental and harmonic frequency bands are phase-locked). Freilich and Guza, [1984] and Elgar and Guza [1985a, 1986] used nonlinear Boussinesq equations to model the shoaling of a spectrum of weakly nonlinear non-breaking waves. They found good agreement between model predictions and observations of the spatial evolution of wave energy spectra and phase speed. Unlike theories for nonlinear, monochromatic waves of permanent form (e.g., shoaling Stokes or Cnoidal waves), the inclusion of interactions from all frequencies in the random wave model allowed accurate predictions of nonlinear statistics (e.g., skewness and asymmetry). These statistics may be important in determining the net direction of cross-shore sediment transport.

By breaking time series up into individual waves, the wave height probability distribution could be found for natural seas. Wave staff data from NSTS [Thornton and Guza, 1983] and photopole data (sea surface elevation measured photographically at marked staffs) from DUCK-85 [Hughes and Borgman,1987] showed that *H*/*h* statistics were always at least qualitatively well modelled by a Rayleigh distribution. Moreover, data from a barred beach, Soldier's Beach, CA, showed that the waves that were actively breaking were not just the largest in the distribution, but were themselves distributed in height [Thornton and Guza, 1983]. Some nonbreaking waves had larger heights than some breaking waves.

These random wave models predict depth-limited energy saturation on simple monotonic beach profiles such as at NSTS (figure 3). However, an important consequence of the probabilistic nature of a random sea is that naturally occurring *H*/*h* ratios in the surf zone (with *H* taken as the root mean square wave height) are roughly 0.4-0.5, about half the value with monochromatic waves. Sallenger and Holman [1985] confirmed the saturation behavior of the incident band on the more complex barred profile of the DUCK experiments [experiment descriptions in Mason *et al.*, 1984, Mason *et al.*, 1987, and Birkemeier *et al.*, 1988]. As in NSTS, observed values of *H*/*d* were well below laboratory results for monochromatic waves (mean value 0.32), but showed a systematic dependence on beach slope. Sat-

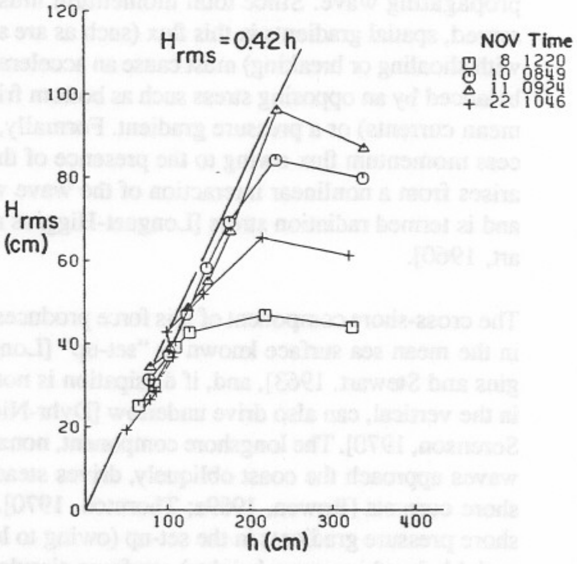

FIGURE 3. RMS wave height vs. local depth for a nearly plane beach profile. Wave height in the inner surf zone appear to be saturated, depending only on local depth (from Thornton and Guza, 1982).

uration behavior of the incident band was also observed in the swash at NSTS [Guza and Thornton, 1982], NERC [Mizuguchi, 1984] (experiment description Horikawa, 1988) and DUCK [Holman and Sallenger, 1985]. In the latter case, swash magnitudes were found to depend on both the beach slope and offshore wave steepness, as expressed in the laboratory-derived surf similarity parameter, ε_0. Confirmation of this dependence from NSTS is not possible due to the limited range of ε available from that dataset.

Mean flows / sea level adjustments

Incident waves can theoretically provide a stress on the water column through the momentum flux associated with the propagating wave. Since total momentum must be conserved, spatial gradients in this flux (such as are associated with shoaling or breaking) must cause an acceleration or be balanced by an opposing stress such as bottom friction (for mean currents) or a pressure gradient. Formally, this "excess momentum flux owing to the presence of the waves" arises from a nonlinear interaction of the wave with itself and is termed radiation stress [Longuet-Higgins and Stewart, 1960].

The cross-shore component of this force produces changes in the mean sea surface known as "set-up" [Longuet-Higgins and Stewart, 1963], and, if dissipation is not uniform in the vertical, can also drive undertow [Dyhr-Nielsen and Sorenson, 1970]. The longshore component, nonzero when waves approach the coast obliquely, drives steady longshore currents [Bowen, 1969a; Thornton, 1970]. Longshore pressure gradients in the set-up (owing to longshore-variable breaking wave heights) can force circulation cells [Bowen, 1969b].

Most early models for set-up and horizontal currents were driven by monochromatic, unidirectional waves [see Basco, 1983, for a review]. Since these uniform waves all break at the same cross-shore position, the forcing of mean currents jumps from zero outside the break point to a maximum value at the break point. The resulting nonphysical discontinuity in the longshore current can be smoothed by the introduction of a large lateral eddy viscosity.

More refined models [Battjes, 1972] for longshore current generation with random waves was tested using the NSTS data during periods when incident wave energy was confined to a relatively narrow range of directions and frequency [Thornton and Guza, 1986]. Because there is no unique breakpoint in a random sea and the onset of breaking is spread over a breaking region, the resulting longshore current profile will show a gradual cross-shore increase in strength. Large values of lateral eddy viscosity are no longer necessary to model the current profile (figure 4). Thus, while eddy viscosity appears important for the monochromatic conditions available in a laboratory, it may not be relevant to the random seas of natural beaches. When monochromatic wave models are applied to a random sea, the values of lateral eddy viscosity obtained by fitting the model to the data do not necessarily relate to actual Reynold's stresses but may instead be simple parameterizations of wave randomness. Additionally, the large values of *H*/*h* observed with monochromatic waves cannot be used in natural situations without a compensating distortion of other model parameters. Monochromatic models very crudely parameterize the physics of longshore currents driven by natural random waves.

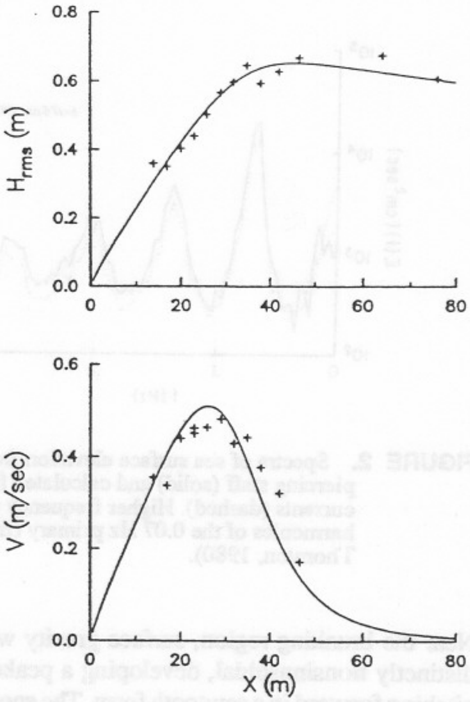

FIGURE 4. Cross-shore profile of incident wave height and the resulting longshore current. Plus signs are data and the solid line is a random wave model. Random wave breaking spreads the breakpoint and removes the requirement for artificial mixing. (From Thornton and Guza, 1986).

The model-data comparisons of Thornton and Guza [1986] were limited to cases with narrow banded incident waves. If the incident wave field is not narrow, for example consisting of two wave trains of different frequencies coming from different directional quadrants, then the radiation stress term that drives longshore currents has two components of opposite sign. However, there are no models describing how energy and momentum are extracted from a breaking, broad-banded wave field. Thus, theory cannot predict whether such a wave field breaks differentially (e.g., one frequency component losing momentum seaward of the other) and drives a longshore current with cross-shore sign reversals, or whether momentum is extracted from both components at equal rates. The NSTS data suggests that the effects of differential breaking are weak. Longshore currents are insensitive to the frequency structure of the radiation stress. Only the total radiation stress is of first order importance to longshore currents [Guza *et al.*, 1986].

The importance of direct wind forcing to mean longshore currents was examined by Whitford and Thornton [1988] using an instrumented sled towed over the barred beach profile at SUPERDUCK. As observed at NSTS, longshore currents were found to be predominantly wave driven, with wind stress contributing only 10-20% of the total forcing. Of course, well outside the surf zone wind stress can become dominant, either by direct forcing or as a result of larger-scale, shelf-wide dynamics.

The vertical structure of longshore flows during SUPERDUCK was found to be near uniform, with only small surface and bottom boundary layers [Whitford and Thornton, 1988].

The cross-shore component of radiation stress theoretically forces the sea level gradient known as set-up, a model confirmed by numerous laboratory experiments [Bowen *et al.*, 1968; Hansen and Svendsen, 1979; Okayasu *et al.*, 1988; Stive and Wind, 1982]. In the field, set-up is not easily measured in the surf zone because of the presence of larger wave signals, but has been measured in the run-up where set-up is a maximum. For the NSTS Torrey Pines data, Guza and Thornton [1981] were able to observe wave set-up with mean values from four-hour runs that showed a noisy but significant trend given by,

$$\bar{\eta} = 0.17 H_0 \qquad \text{(EQ 3)}$$

in approximate agreement with laboratory results.

Wave set-up was also obtained from digitized film records of swash, collected during DUCK82. Holman and Sallenger [1984] found that the relative setup (normalized by H_0) was typically larger than had been previously reported and depended on ε_0, being larger during reflective wave conditions than during dissipative situations. Again, a great deal of scatter was found. The NSTS results were consistent with the extrapolation of their data to high ε_0.

Since the cross-shore momentum equations involve the balance of two strong forces, the wave-driven radiation stress gradient and the pressure gradient of set-up, relatively weak vertical differences in the balance can drive cross-shore mean flows (undertow) with strong vertical shears.

Infragravity band processes

The fact that natural waves are not monochromatic, but occur as a random process has a further, important consequence. Modulations of wave height (wave grouping) result in fluctuations in radiation stress. These, in turn, can drive flows at the time and space scales of the modulation, significantly longer than the incident waves. These long waves, with typical periods of 0.5-5.0 minutes on exposed ocean coasts, are known as "surf-beat" or "infragravity waves" [Munk, 1949; Tucker, 1950].

Measurements made during the 1970's, with only a few sensors deployed simultaneously, showed that infragravity waves are at least partially standing in the cross-shore direction [Suhayda, 1974; Huntley, 1976], and in the inner surf zone may contain more energy than the incident wind and swell waves [Huntley, 1976; Holman *et al.*, 1978]. These early measurements could not reveal whether the observed infragravity energy was propagating from deep water toward the beach where it reflects and radiates back out to sea (leaky waves), generated in shallow water and refractively trapped in the nearshore wave guide (topographic edge waves), or generated locally in response to grouping of the local wind waves.

Recently, our understanding of the infragravity band has been greatly extended by the results of large field experiments. The previously reported standing wave structure in the cross-shore direction was always observed, resulting in spectral peaks and valleys at predictable frequencies (figure 5) for which wave nodes corresponded to instrument position [Guza and Thornton, 1985; Hotta *et al.*, 1981; Sal-

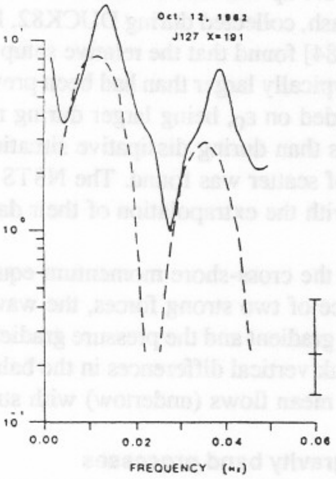

FIGURE 5. Measured (solid line) and modelled (dashed) cross-shore velocity spectra for the infragravity band. The hills and valleys in the spectra result from correspondence of nodes and antinodes of the standing waves with the instrument position. (From Sallenger and Holman, 1987).

lenger and Holman, 1984, 1987]. Variance in the infragravity band increased toward the shoreline, comprising up to 50% of the flow variance at the bar crest and up to 75% of the swash energy during SUPERDUCK. In contrast to the saturation behavior of the incident band within the surf zone, infragravity band energy was found to vary approximately linearly with offshore wave energy in both the swash (figure 6) and surf zone currents [Guza and Thornton, 1982; Sallenger and Holman, 1984]. The essential result of these observations is that on dissipative beaches (i.e., storm conditions, large ε_0), the spectrum at the shoreline is dominated by energy at infragravity frequencies. Thus, near the shoreline, the principal manifestation of large incident wind and swell waves and a wide surf zone will not be an increased incident band energy, but instead will be energetic infragravity waves [Guza and Thornton, 1982].

Alongshore arrays of current meters at both NSTS sites and at SUPERDUCK were used to estimate the longshore wavenumber-frequency spectrum of infragravity motions in the very nearshore. Such a spectrum allows differentiation between high wavenumber edge waves trapped in the nearshore wave guide, and leaky modes that escape offshore. As is shown in figure 7, low mode edge waves contributed significantly to run-up, and the longshore component of the infragravity wave velocity field. However, the low mode signal in the cross-shore velocity field is usually masked by either high mode edge, leaky, or locally forced waves [Huntley *et al.*, 1981; Oltman-Shay and Guza, 1987].

Far Infragravity Waves

Analysis of cross-shore and longshore velocity from the bar trough during SUPERDUCK showed energetic, coherent motions with time scales of hundreds of seconds (defined as the far infragravity band) and longshore wavelengths of hundreds of meters [Oltman-Shay *et al.*, 1989] (figure 8). The longshore phase speeds of these motions increased with increasing mean longshore current velocity, but were always much slower than those of any known gravity wave motion. Bowen and Holman [1989] explained the observations in terms of meanders arising from a shear wave instability of the mean longshore current. The period and growth rates of the instability were shown to theoretically vary with the maximum shear of the current, suggesting the general importance of these waves on barred beaches where the shear over the bar may be large. An alternate explanation for weak motions in this band, based on observations on the monotonic Torrey Pines beach profile during NSTS, models the low frequency signals in terms of a migrating rip current system, driven by a slowly beating incident wave field [Tang and Dalrymple, 1988].

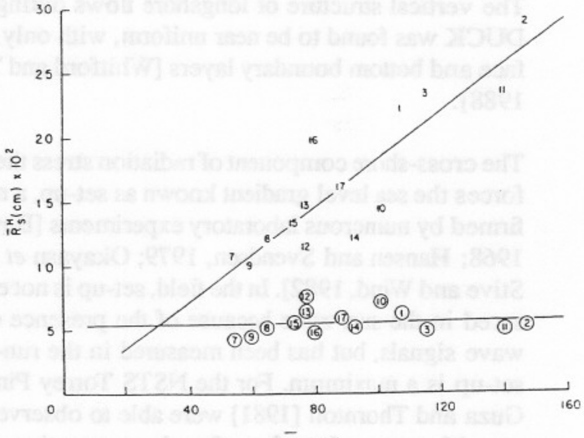

FIGURE 6. Magnitudes of the swash excursions in the incident band (circled) and infragravity band (uncircled) as a function of offshore wave height. The incident band is saturated, the infragravity band is not. (From Guza and Thornton, 1982).

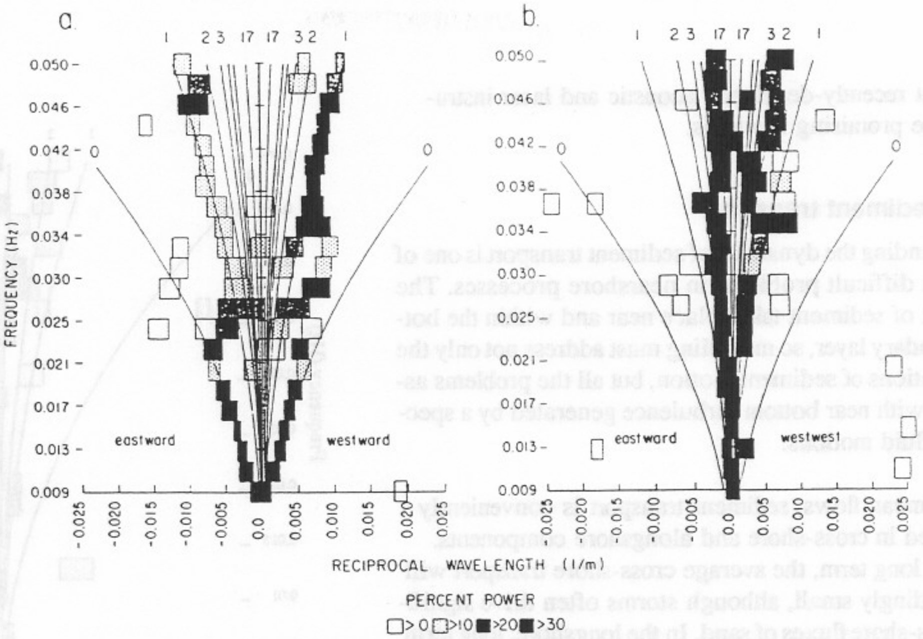

FIGURE 7. Frequency-wavenumber spectra for the infragravity band based on a) longshore current, and b) cross-shore current. Frequency is on the vertical axis, wavenumber on the horizontal with eastward and westward progressive motions marked (the beach faced south). Shaded boxes, indicating concentrations of energy, tend to fall along theoretical edge wave dispersion curves (solid lines), indicating the importance of edge waves in the infragravity band. (From Oltman-Shay and Guza, 1987).

4.2 Small scale motions

Much of the incident wave energy propagating towards the shoreline is dissipated via high frequency turbulent motions. The associated momentum fluxes provide a stress that can drive secondary flows, including undertow. Although laboratory studies have provided some information about the dynamics of turbulence in oscillating flow, field measurements of small scale motions are very limited. Moreover, it is difficult to separate turbulent motions from the high frequency wave components of the wave field.

Production of small scale turbulence occurs at both the surface and the bottom boundaries. The relative magnitudes of turbulent energy at these boundaries and the scales of penetration of turbulence into the fluid interio can be quite variable.

Surface-intensified turbulence results from wave breaking. Laboratory observations of the depth of penetration of turbulence, inferred from bubble observations, show a dependence on the breaker type [Miller, 1976]. For spilling breakers (high ε_0) turbulence is maintained near the surface, while for plunging breakers (intermediate ε_0) the entire water column is mixed (for low ε_0, no breaking occurs). In addition, entrainment of bubbles is expected to yield stratification and buoyancy effects.

Turbulence is also generated in the bottom boundary layer. Theory suggest that under waves the vertical scaling varies as u_*/f, where u_* is the friction velocity and f the wave frequency [Grant and Madsen, 1979]. Under reflective conditions for which incident frequencies dominate, the boundary layer may only be a few centimeters thick, while under the energetic infragravity motions of dissipative beaches, the wave-driven boundary layer is expected to fill the water column. Again, the importance of proper scaling is apparent.

There is a complex interaction between the bottom boundary layer and bottom microtopography. Ripples can form rapidly (O(10^2 sec)) or disappear in response to the bottom stress, and in turn, can significantly alter that stress. Stratification can be induced within the boundary layer by the suspension of sediment.

Our understanding of small scale fluid processes has been severely limited by our inability to sample in field conditions, but recently-developed acoustic and laser instruments are promising newtools.

4.3 Sediment transport

Understanding the dynamics of sediment transport is one of the most difficult problems in nearshore processes. The transport of sediment takes place near and within the bottom boundary layer, so modelling must address not only the complications of sediment motion, but all the problems associated with near bottom turbulence generated by a spectrum of fluid motions.

As with mean flows, sediment transport is conveniently considered in cross-shore and alongshore components. Over the long term, the average cross-shore transport will be exceedingly small, although storms often drive significant cross-shore fluxes of sand. In the longshore, long term mean transports can exist, for instance in the southward littoral drift of the American east coast, and can be interrupted by structures or inlets, causing erosion of down-drift beaches.

The dynamics of vertical fluxes of fluid momentum are strongly affected by mobile sediment. In the water column where sediment concentrations are small, momentum fluxes are caused primarily by fluid turbulence. The weight of sediment is supported by this turbulence and is referred to as suspended load. However, as the bottom is approached sediment concentrations increase until, for volume concentrations exceeding 9% [Bagnold, 1963], intergranular collisions become the primary mechanism for vertical momentum flux. That transport which is supported by these collisions is known as bedload transport. The vertical scale of this transition varies rapidly with the time scale of the wave motions .

The complications associated with sediment transport include:

- suspension depends intimately on the details of the turbulent bottom boundary layer and turbulence in the water column,
- sediment motion only occurs for stresses exceeding a threshold, introducing a nonlinearity in the system,
- the non-uniform size of sediment grains affects both the threshold of grain motion and the subsequent transport,
- interstitial, or pore, water can have dynamic effects including vertical pressure gradients and (small) velocities that will affect the threshold of sediment movement and the structure of the bottom boundary layer,
- phase lags commonly exist between fluid stress, suspension, and settling,
- the characteristics of the driving fluid motions (mix of mean, wave and turbulent motions) changes dramatically with distance from the shoreline.

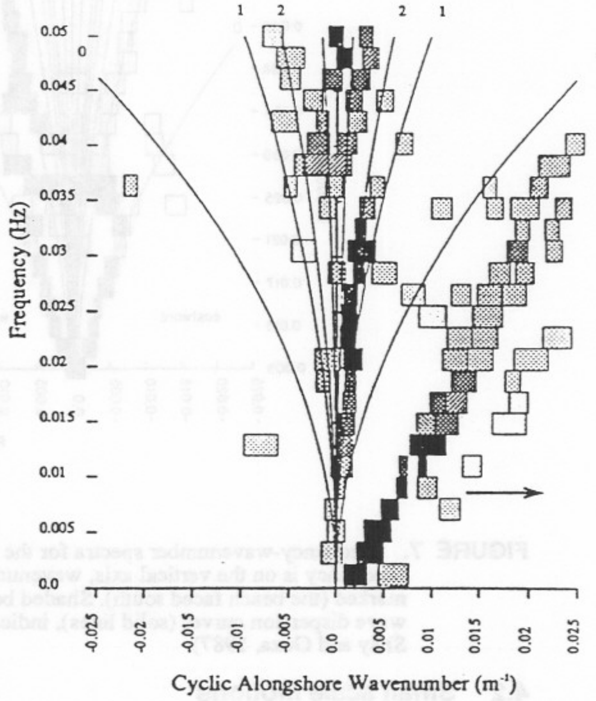

FIGURE 8. Frequency-wavenumber spectrum from SUPERDUCK. The linear ridge of energy on the right, well away from the edge wave dispersion curves, represents shear waves at far infragravity frequencies, propagating in the direction of the mean longshore current (indicated by arrow). (From Oltman-Shay *et al*, 1989)

Existing transport models [e.g., Bowen, 1980; Baillard and Inman, 1981] are largely extensions to theories developed for the unidirectional conditions of river or eolian transport. These nearshore transport models assume that the unidirectional transport model is correct, and explore the large-scale consequences of oscillatory flow. They are strictly only valid in a limited parameter space. Bowen [1980] used this approach to investigate and parameterize the roles of mean currents, wave asymmetry (parameter-

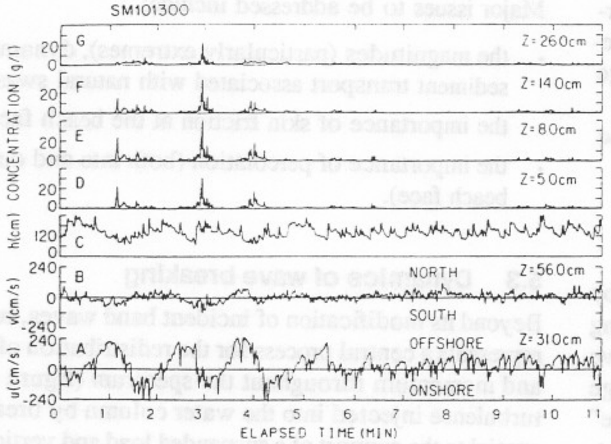

FIGURE 9. Time series of: a) cross-shore velocity, b) longshore velocity, c) sea surface elevation, and d-g) suspended sediment concentration for the indicated levels above the bed. For this inner surf zone case, the importance of infragravity motions on the time scale and magnitude of the suspended load is apparent (from Beach and Sternberg, 1988).

ized by the skewness of the time series) and infragravity motions on the resulting equilibrium beach profile.

Field verification of models has been difficult due to the high spatial and temporal sampling requirements and the ruggedness of the surf zone environment. However, with recent developments in both acoustic and optical instruments, field data are beginning to become available. For example, figure 9 shows variations of suspended sediment concentration with time and height above the bed under energetic waves ($H_s \approx 4$ m), illustrating the importance of infragravity motions (the dominant period of fluid motion was 100 seconds) on sediment transport under extremely dissipative conditions [Beach and Sternberg, 1988]. Huntley and Hanes [1987] measured wave-induced fluxes near the bed, finding shoreward transport associated with the incident band but an opposing seaward transport driven by infragravity motions (figure 10). However, with these and several other exceptions, there have been few field studies to test sediment transport models.

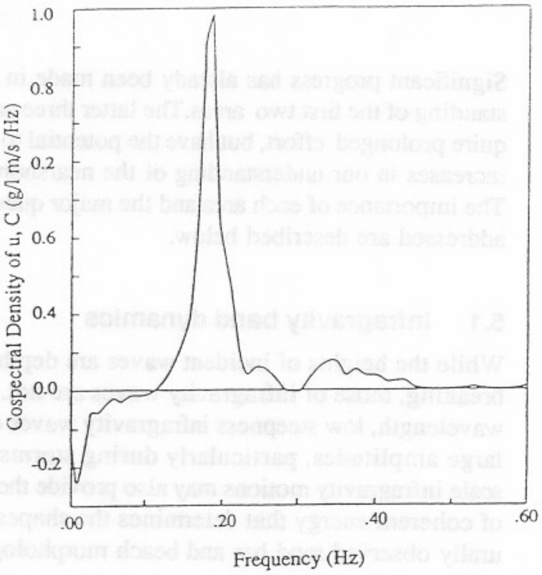

FIGURE 10. Cospectrum of cross-shore velocity and sediment concentration. Positive peak indicates shoreward sediment transport of incident waves, negative indicates seaward transport by infragravity motions. (From Huntley and Hanes, 1987).

5.0 Priority Research Areas

Incident waves drive the entire nearshore system, hence our understanding of incident band dynamics forms the foundation of all nearshore processes models. Excellent results have been achieved in theory, laboratory research, and field studies, and the workshop placed a high priority on continuation of these efforts.

Considering further, the workshop participants reached a consensus on five priority areas for future research. While these topics are important for a better understanding of the nearshore, they should not be viewed as areas of exclusive focus. Listed in order of increasing complexity (but without regard to scientific priority) the five recommended areas are:

1. infragravity band dynamics
2. swash dynamics
3. the dynamics of wave breaking
4. bottom boundary layer processes
5. the dynamics of small-scale sediment processes

Significant progress has already been made in our understanding of the first two areas.The latter three areas will require prolonged effort, but have the potential to yield large increases in our understanding of the nearshore system. The importance of each area and the major questions to be addressed are described below.

5.1 Infragravity band dynamics

While the heights of incident waves are depth limited by breaking, those of infragravity waves are not. Thus, long wavelength, low steepness infragravity waves can achieve large amplitudes, particularly during storms. The large scale infragravity motions may also provide the "template" of coherent energy that determines the shapes of the naturally observed sand bar and beach morphologies.

Major issues to be addressed include:

- the forcing of long waves by a random, directionally-spread, incident wave field,
- the relative importance of trapped, leaky and forced modes,
- the dissipation of long wave motions in the presence of shorter incident waves and strong mean currents,
- interactions with a complex sand bar topography.

It is recognized that results will vary systematically with some measure of the large-scale beach steepness.

5.2 Swash dynamics

The swash is that portion of the wave that rushes up the "dry" beach face. The flow is supercritical and occurs in a very thin sheet, strongly subject to the friction on and percolation into the beach face.

Swash motions are a result of the non-breaking components of the infragravity and incident band energies. Thus the spectral composition will vary with the beach steepness and incident wave characteristics, as represented, for example, by the surf similarity parameter, ε_0. The leaky mode portion of the swash represents energy that will be radiated away from the nearshore, so can represent an important term in the nearshore budget of energy and momentum. Sediment transport in the swash can be large, and consequently swash may be an important agent of coastal erosion.

Major issues to be addressed include:

- the magnitudes (particularly extremes), dynamics and sediment transport associated with natural swash,
- the importance of skin friction at the beach face,
- the importance of percolation (both into and out of the beach face).

5.3 Dynamics of wave breaking

Beyond its modification of incident band waves, breaking represents a central process for the redistribution of energy and momentum throughout the spectrum (figure 1). The turbulence injected into the water column by breaking is crucial to the support of a suspended load and vertical variability in the breaking process probably contributes to the generation of undertow.

Prevailing models of wave breaking are primarily empirical. Research questions include:

- initiation and type of wave breaking (spilling/plunging) as a function of incident wave conditions and nearshore topography,
- the prediction of wave statistics for random waves through the breaking region and surf zone,
- vertical gradients in turbulence generated by wave breaking,
- buoyancy effects of bubble entrainment caused by wave breaking.

5.4 Bottom boundary layer processes

The interaction of waves with sediment largely occurs in and near the bottom boundary layer. Moreover, bottom friction is the dominant dissipation mechanism for long waves and mean flows, hence determines the relative importance of free and forced motions.

Some parts of a complete theory currently exist for the regions seaward of the surf zone, but they need to be extended to include a full range of frequencies. No boundary layer models exist for the surf zone. Important issues include:

- turbulent boundary layers under combined waves and currents,
- the interaction of the boundary layer with small scale bed forms,
- the effects of sediment-induced stratification,

- the effect of turbulence induced by surface wave breaking on the bottom boundary layer.

5.5 Small scale sediment processes

The direct effects of sediment transport on large scale fluid motions is small, primarily consisting of the introduction of stratification in the boundary layer and modification of the bottom roughness through microtopography. However, changes in the bathymetry that forms the bottom boundary condition for waves and currents are the result of cumulative transport, and can be significant on a time scale as short as several hours during storms. Thus, our ability to predictively model the dynamics of the nearshore system is limited by the absence of tested sediment transport theories.

Owing to the complexity and the difficulty of collecting measurements of relevant variables in the field or the laboratory, the current understanding of the dynamics of sediment transport lags that of nearshore fluid dynamics. For example, no fundamental momentum-based equations of motions exist for either the initiation or transport of sediment by fluid stresses. However, some progress has recently been made with the development of new techniques (acoustic, optical and laser Doppler) that allow sampling at the temporal and spatial scales of the turbulence.

The study of sediment transport under waves is young, so many important research issues exist, including:

- the development of governing equations for the initiation of sediment motion,
- the role of pore water motion and pressure gradients on the initiation and maintenance of sediment transport,
- the effects of having a distribution of grain sizes on the initiation and rate of sediment transport,
- the transport under a spectrum of random waves combined with mean flows.

The study of sediment transport under oscillatory wave and mean currents on a sloping beach is an extremely large and extremely valuable undertaking. While all the tasks discussed will entail an ordered set of steps, this is especially true for sediment transport.

6.0 Synthesis

As a field of ocean surface waves approaches the beach, nonlinear interactions transfer energy away from the incident swell and wind waves to motions at both higher and lower frequencies. Energy transfers to higher frequencies result in the evolution of wave profiles from sinusoidal shapes at the seaward edge of the nearshore region to the asymmetric or pitched-forward shapes of waves about to break. Turbulence generation by both surface breaking and in the bottom boundary layer also represents an important transfer of energy to higher frequencies. To lower frequencies, groups of wind waves will force infragravity waves, including edge waves trapped near the coast and leaky modes that reflect from the beach. In addition, strong mean flows can be forced in both the cross-shore and longshore directions, the latter being unstable to shear waves at far infragravity frequencies.

The dynamics of these nonlinearities depends strongly on the pre-existing beach topography (for example, the beach steepness), so parameterizations of the topography must be an integral part of the scaling of natural beach processes.

However, the bottom topography of an erodible beach is itself a response to the wave motions. On the time scale of minutes, ripples and bottom roughness can change, while the entire morphology of a beach and sand bar system can be completely altered over a few hours during a storm.

Although substantial progress toward understanding the dynamics of nearshore fluid motions has been made, further research is needed in many areas. Several of these, including study of the dynamics of infragravity waves and wave run-up, may yield substantial results with only a moderate concentration of effort. Others, including research on breaking processes, bottom boundary processes and the dynamics of sediment transport, will require major efforts over a long time. For these, progress will be made in increments, with each an important step in our ability to model and deal with our coastlines.

The prognosis for progress is good, as is evident from the advances made in recent years. The motivation to continue that progress is strong now and strengthens with the slow rise of sea level. There is no substitute for the knowledge that we seek.

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Appendix II

Working Group Reports

Nearshore Fluid Motions: Large and Small Scales

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May 25, 1989

Introduction

The objective of the fluid mechanics group is to understand the transfer of wave-induced momentum and energy from deep water through the shoaling zone onto the beach face. Our working hypothesis is that the nearshore motions are driven by the wave momentum and it can be modelled based on known physics.

Figure 1[*] shows the key elements of the transfer of momentum within the nearshore zone. The figure is designed to depict an offshore coordinate vertically (with the top of the figure representing the offshore boundary) and a frequency scale laterally (high frequency on the left and low frequency on the right). Starting at the top of the figure, the wave climate is to be specified as a boundary condition. The first oval is the shoaling processes, whereby the input waves shoal, refract (on depth variations and current fields), diffract, and nonlinearly interact with each other. The nonlinear processes can produce higher and lower frequency waves, which are depicted in the rectangular boxes.

The next step inshore is the breaking process, primarily that which occurs in the surf zone. Breaking leads to turbulent motions, high frequency waves, low frequency waves, that is, the infragravity waves, and to three-dimensional circulation. There is an interaction implicit between all of these waves, as nonlinearity will couple all of these wave and turbulent motions. The three-dimensional circulation includes steady (or slowly varying) longshore currents, rip currents, and undertow. These motions can be significantly affected by the presence of large scale motions, such as the tides and the wind field.

Swash motions, primarily run-up, is largely the shoreline expression of the infragravity waves, although wind waves, in the absence of infragravity waves, also produce a run-up. These fluid motions, involving large excursions of water on the beach face, may play a large role in sediment transport.

Surf zone instabilities, such as the instability of the longshore current (the newly-discovered so-called far infragravity wave motions) or of the nearshore circulation system, can lead to large spatial and temporal variations in the current field.

All of the key elements and processes discussed above involve interactions with one another and interactions with the large and small scale sedimentary structures on the bottom

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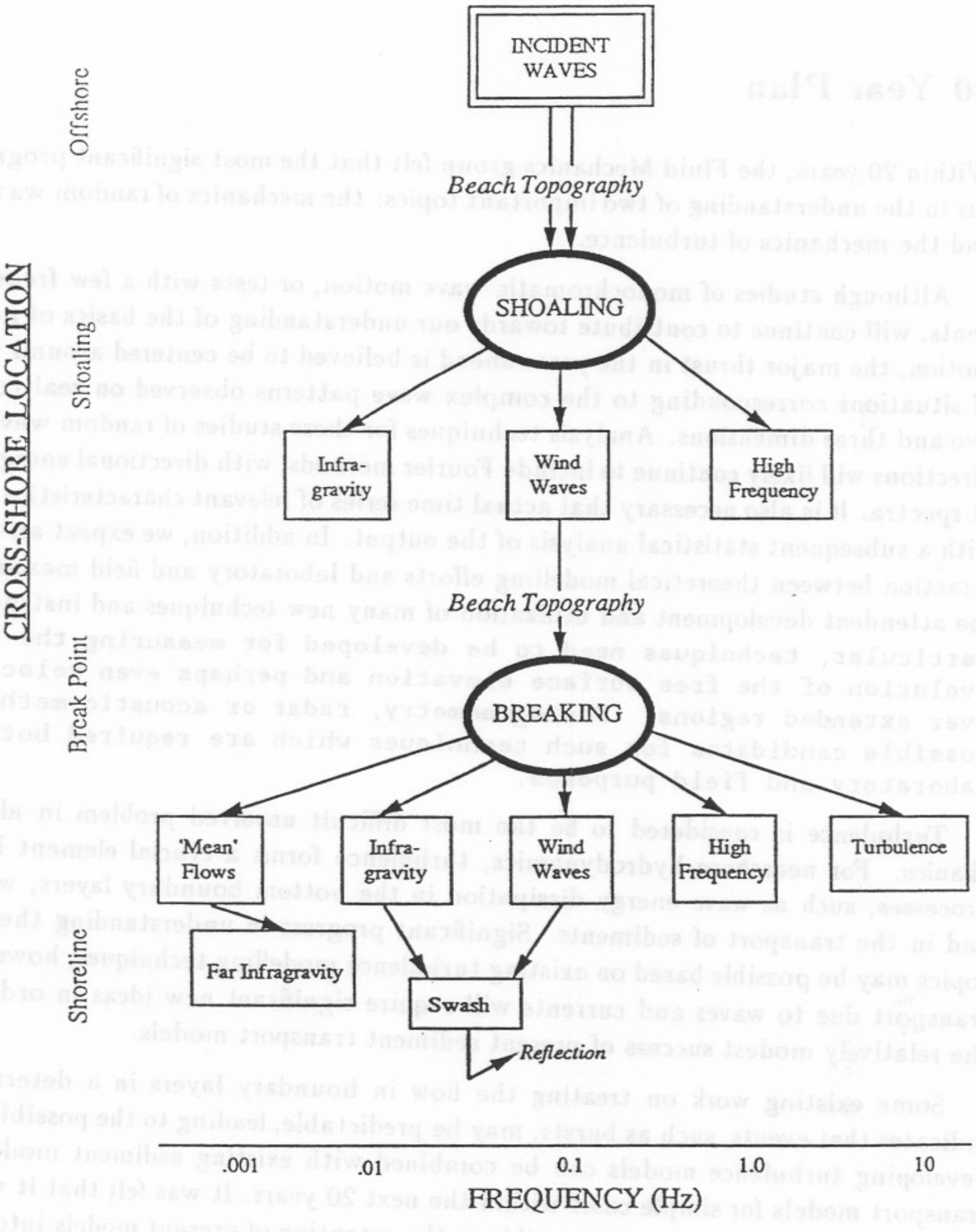
[*] Figure 1 has been drafted in reverse, left is now right.


INCIDENT WAVES
Beach Topography
SHOALING
Infra-gravity
Wind Waves
High Frequency
Beach Topography
BREAKING
Mean' Flows
Infra-gravity
Wind Waves
High Frequency
Turbulence
Far Infragravity
Swash
Reflection
CROSS-SHORE LOCATION
Offshore
Shoaling
Break Point
Shoreline
.001
.01
0.1
1.0
10
FREQUENCY (Hz)

and, to some extent, the concentration of sediment in the water column.

20 Year Plan

Within 20 years, the Fluid Mechanics group felt that the most significant progress would occur in the understanding of two important topics: the mechanics of random wave phenomena and the mechanics of turbulence.

Although studies of monochromatic wave motion, or tests with a few frequency components, will continue to contribute towards our understanding of the basics of nonlinear wave motion, the major thrust in the years ahead is believed to be centered around the modelling of situations corresponding to the complex wave patterns observed on real coasts, both in two and three dimensions. Analysis techniques for these studies of random waves from many directions will likely continue to include Fourier methods, with directional energy spectra and bi-spectra. It is also necessary that actual time series of relevant characteristics be calculated with a subsequent statistical analysis of the output. In addition, we expect an intensified interaction between theoretical modelling efforts and laboratory and field measurements with the attendent development and utilization of many new techniques and instruments. In particular, techniques need to be developed for measuring the temporal evolution of the free surface elevation and perhaps even velocity fields over extended regions. Photogrammetry, radar or acoustic methods are possible candidates for such techniques which are required both for laboratory and field purposes.

Turbulence is considered to be the most difficult unsolved problem in all of fluid mechanics. For nearshore hydrodynamics, turbulence forms a crucial element in several key processes, such as wave energy dissipation in the bottom boundary layers, wave breaking, and in the transport of sediments. Significant progress in understanding the first of these topics may be possible based on existing turbulence modelling techniques; however, sediment transport due to waves and currents will require significant new ideas in order to improve the relatively modest success of present sediment transport models.

Some existing work on treating the flow in boundary layers in a deterministic sense indicates that events, such as bursts, may be predictable, leading to the possibility that these developing turbulence models can be combined with existing sediment models to provide transport models for simple cases within the next 20 years. It was felt that it was important to start on this work as soon as possible as the extention of present models into the surf zone is a difficult task.

5 Year Plan

The working group identified four major elements for which significant theories and critical experiments (lab and field) are lacking and which should be addressed within the next five years. These topics are:

- Breaking
- Infragravity Wave Generation, Reflection, and Dissipation

- Swash
- Bottom Boundary Layer

Subsequent discussions focussed on these four critical topics. Other topics, deemed to be important, were not included on the list, as either considerable theory presently exists or work is presently underway on these topics.

Breaking

The process of wave breaking produces turbulence, bubbles and dissipation of energy. The incident waves are radically modified by breaking in an unknown manner. Without a detailed description of the effects of breaking on the wave momentum flux, it is not possible to provide a model for all of the fluid motions in the surf zone, even in a statistical manner.

Original work on breaking has resulted in the so-called depth-limited (or the spilling breaker) assumption that the wave height is proportional to the water depth. While this model has served a useful life, it does not indicate how to treat the realistic case of the breaking of a directional sea state. One-dimensional bore models have provided a path for determining some of the properties of a breaking wave train, and may lead to more general models. It is likely that a new paradigm is needed, as the problem of breaker type (say, plunging or spilling) will need special treatment.

In the laboratory, large scale spatial measurements of breaking should be carried out. Due to the costs, this may require large multi-investigator studies, as is the case for field studies. Further, the bottom boundary layers under breaking waves and their interaction with the breaker-generated turbulence will require significant laboratory modelling. A problem which may be important in the lab is that bubbles in fresh water behave differently than in sea water. New equipment such as LDV's and radar doppler may provide significant help.

In the field, wave information is needed within the surf zone as a function of space, time and the existing environmental conditions. The advantage of the field is the existence of many other variables (such as low frequency motions which may have an O(1) effect on the breaking process), which are not necessarily replicated in the lab.

New field equipment, such as a small field LDV or acoustic doppler devices may help to resolve some of the small scale motions which occur in the crest region or forward face of a breaking wave.

Infragravity Wave Generation

The presence of energetic low-frequency wave motion in the surf zone, which plays a large role in the circulation, swash, and sediment transport in nature, dictates that we understand the generation, reflection and dissipation of these waves. Some theory exists for their generation (~~Gallagher, Guza and Davis~~); however these models must be extended, so that the entire incident spectrum of waves is included, rather than a few incident wave components. New aspects must be added to the theories, such as bottom boundary layer damping and the wave–wave interaction (for short and long waves).

The laboratory can provide a role in the verification of these models; however, due to the long wave lengths possible and the standing nature of some of the long wave modes, wave absorption is a key facet of any laboratory experimentation. Active wave absorption is likely to be required and the side walls of any basin must be absorbing as well.

In the field, experiments to identify all possible wave modes need to be carried out. These experiments require very high spatial resolution, which means dense arrays of current meters or the use of new equipment, such as the following: photogrammetry or video methods, radar, or acoustical sensing methods. Further, field experiments are beginning to require long data records (many hours of stationary data), which indicates that experiments in micro-tidal regimes is necessary.

Swash

The swash is the portion of the wave that rushes up the 'dry' beach face. The flow is supercritical and occurs in a very thin sheet, strongly subject to the friction on the beach face. Some of the fluid percolates into the beach, making it very difficult to generate an appropriate theory. Yet for swash sediment transport, the velocity profiles and surface elevations of the swash are needed.

From a theoretical perspective, any modelling will need to examine the coupling with the infragravity waves (in terms of energy and momentum transport offshore by reflection and radiation). Other questions to be answered are do infragravity waves break, creating a swash motion, and how do we predict overwash?

The laboratory provides an environment for detailed measurements of the swash velocities and surface elevations. The use of a porous mobile (sand) bed is necessary. As with all laboratory studies, scaling may be a source of problems. Further, reflection of the long wave motion from the wavemaker is a problem which needs to be addressed.

In the field on mild beaches, the prediction of swash motions requires knowledge of the infragravity wave spectrum. For all beaches, an offshore boundary conditions will need to be measured. Much of the field work may need to be guided by the theory which will be developed. New instrumentation (LDV) may play an important role, although existing technology (video, hot film) may suffice.

Bottom Boundary Layer

The interaction of the wave motion with the sediments largely occurs in and near the bottom boundary layer. Some parts of a complete theory currently exists for the region offshore of the surf zone, but it needs to be extended to include a full range of frequencies. Further the following important points need to be addressed by researchers in this area: turbulent boundary layers under combined waves and currents, the interaction of the boundary layers with small scale bed forms, the effect of high sediment concentrations on the boundary layer, and, in the surf zone, the effect of turbulence induced at the surface on the bottom boundary layer. In the surf zone, there is no theory extant.

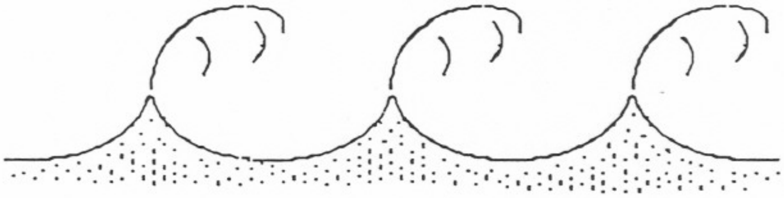
Both the laboratory and the field will play a role in elucidating the physics of the flow in the boundary layer. Measurements of the bed shear stress should prove to be helpful. In this area particularly the use of new instrumentation will be invaluable.

SUMMARY OF SMALL SCALE FLUID AND SEDIMENTARY PROCESSES MEETING

Session of 26 April 1989 A.M.

Five general topics were considered to be essential for further research in small scale fluid and sedimentary processes. These are listed below with summaries from each of the working groups.

1. Fluid-Bedform Interaction



A. Fundamental considerations

Bedforms are of primary importance in sediment transport problems and it is essential to progressi from a roughness parameterization using an empirical "drag coefficient" approach to more physically based models which deal with the concepts of:

1. flow separation vortices, bursting
2. grain entrainment
3. bedform change in relation to flow conditions
4. the use of fundamental turbulent sediment transport models

B. General guidelines for future research

1. Monochromatic experiments should be shifted to more realistic wave characterizations in physical models unless absolutely necessary.
2. The response time of sediment bedforms to changing flow conditions should be included in fluid-bedform research.
3. Wave-current interaction experiments including bedforms with both codirectional and perpendicular flow combinations are essential.

4. Experiments addressing total sediment load under various combinations of waves and currents are of importance.

C. Experimental approaches

1. Sophisticated laboratory experiments can have relevance but should incorporate a 3-D basin, acoustic system to analyze sediment transport, and image analysis approaches. The laboratory studies are a first step in calibrating, verifying, or guiding theoretical models.
2. Carefully directed field experiments are necessary to address fundamental boundary layer mechanics and bedform response to changing flow conditions. Field experiments also are a necessary aspect to apply laboratory modeling and to verify and guide theoretical models.

2. Motions of Many Time Scales--Unsteady Flows

The surf zone is comprised of fluid motions of many time scales combined in complex ways. Long term advances in sediment transport problems must recognize and account for these motions.

A. Objectives

The objectives of this research are to identify and quantify the characteristic features of unsteady boundary layer flows which are relevant to sediment motion in the nearshore.

B. Specific considerations

The major problems to be considered include:

1. acceleration effects associated with incident waves (including pore water flows) and spatial and temporal variations;
2. interaction between scales of motion such as infragravity flows and incident wave bands;
3. vector direction changes within the nearshore;
4. beach slope as an additional vector effect;
5. the relevant time scales of sediment response.

C. Approach

The approach to carrying out meaningful research on this problem includes laboratory and field experimentation and modeling. Experimental approaches should begin with flat bed sheet flow conditions first and evolve towards more realistic conditions.

Some instrumentation is available, i.e., shear probes and fiber optics, which might allow near-bed measurements; however, remote sensors to measure fine resolution of appropriate parameters may be necessary (e.g., acoustic methods?).

Model evaluations should accompany experimental work to determine how far existing simple flow and sediment transport models can be extended to unsteady flow conditions. It is also expected that appropriate turbulent event models will be necessary which should describe characteristic eddy shapes and turbulent statistics.

3. Turbulent Flow

The structure and characteristics of turbulent flow within the surf zone, although largely unknown, obviously play a key role in surf zone mechanics and sediment transport. Turbulence generated from strong boundary-shear flows and breaking waves are spatially separated but probably intermix in complex ways. These processes in modeling boundary shear and sediment transport may rely to a great extent on improved knowledge of turbulent flow characteristics both within and outside the surf zone.

Possible ways to address this problem include:

a) laser doppler velocity measurements of profiles through the water column and into the seabed;

b) acoustic measurements of sediment and bubble distributions;

c) photography and digital image processing.

Analysis and modeling approaches include relevant methods of separating coherent wave motions from turbulent structure, and the formulation of appropriate equations to represent turbulent structure.

4. Granular-Fluid Interactions

The consideration of granular-fluid interactions is primarily related to the boundary-layer region and includes interstitial dynamics, grain-grain interactions for high concentration sediment transport, grain-fluid interactions, and suspension dynamics for turbulent suspensions. A systematic iteration between experiment and theory/modeling efforts is essential to improve our understanding of sediment response to fluid flows in the near-bed region. A summary of experimental needs coupled with theory/modeling progress is given below.

	Experimental Needs	⟷	Theory/Model (unsteady forcing)
Interstitial dynamics (within bed)	P, $\underline{u}$ (?)		
Grain-grain interactions	$\underline{\underline{c}}$, $\underline{\underline{U}}_f$, $\underline{U}_g$		
Grain-fluid interactions	c, $\underline{U}_f$, $\underline{U}_g$		
Suspension	c, U_f, $\underline{U}_g$		

Legend: c = sediment concentration*
U_f = fluid velocity*
U_g = grain velocity*
P = pressure
$\underline{\hspace{1em}}$ = 5 yr measurement (theory/model) expectation
$\underline{\underline{\hspace{1em}}}$ = >5 yr measurement (theory/model) expectation
no underline (---) = present measurement (theory/model) ability
* = measured at 10 Hz rate

5. Swash/Backwash

The swash/backwash region of beach is considered to be an important element of the nearshore. In spite of its accessability, comprehensive field experiments are lacking primarily due to lack of instrumentation. Not only is there an absence of comprehensive theory to work from, but a data set including flow and sediment movements does not exist. Future research to address this problem includes:

	Theory	Lab	Field
a) Fundamental description of flow (surface to within bed)	x	xx	xxx
b) Temporal and spatial turbulence field			xxx
c) Sediment transport relationships (suspension, deposition, granular flows, etc.)			xxx

The general approach to studies in the swash/backwash region includes:

A. Field experimentation to describe the system

1. Flow description
    - water surface → within bed
    - spatially -- inner surf zone → limit of uprush
    - turbulence characteristics (temporal and spatial)
2. Intergranular characteristics
    - sediment texture
    - permeability
    - pore pressures
3. Sediment movements
    - near-bed concentrations, suspended sediment concentrations, ∇T

B. Laboratory experimentation

Design laboratory experiments to physically model relevant field conditions. May provide an important component to theoretical and predictive capabilities:

1. design of laboratory experiments guided by field measurements
2. verification of laboratory swash/backwas flows with field
3. emphasis would be on flow kinematics--reproduction of turbulence and sediment motions may not be possible

C. Theoretical/computer modeling

No comprehensive theory exists and theoretical elements may include:

1. decelerating turbulent flows charged with sediment and inheriting turbulence characteristics from prior conditions
2. percolation or loss of water into bed
3. accelerating boundary shear flows reaching high Froude numbers
4. hydraulic jump
5. importance of pore pressures

D. Necessary instrumentation includes methods to measure:

1. sediment concentration profiles
2. velocity profiles
3. turbulence characteristics
4. pore pressures

Instruments are presently available to imitate swash/backwash experiments; however, future development will be required as more detailed observations become necessary.

SMALL-SCALE SEDIMENT TRANSPORT

The Small-Scale Sediment Transport Group (the S^3-group) defined their objective as:

> The development of dynamically-based three-dimensional models for the quantitative understanding of sediment transport mechanics in the nearshore environment.

Due to the composition of the S^3-group it was decided to limit the interpretation of the term "sediment" to "cohesionless, granular sediments." Furthermore, the S^3-group used as its definition of the term "nearshore" the coastal region in which wind-waves play a dominant role in fluid-sediment interaction processes. For convenience the "nearshore environment" may be thought of as consisting of three separate (but overlapping) regions: the swash zone, the surf zone, and the offshore zone. According to the above definition of the "nearshore environment" the offshore zone may extend to the shelf break--at least during severe storms.

LONG-TERM GOALS

During the discussion of long-term goals for small-scale sediment transport modeling the S^3-group made the following bold assumption regarding the state of the art of turbulence modeling within the next decade:

> Efficient numerical models of turbulent flows in the nearshore environment will be available to any desired level of complexity, resolution, and accuracy.

This assumption clearly refers to turbulence modeling of flows over a concrete beach, i.e., in the absence of mobile-bed effects, and presumes dramatic developments both in the theory of turbulence modeling and in available computational powers, e.g., the availability of pocket calculators rivaling the computational powers of today's mini-computers. These assumptions may have been considered far-fetched, even unrealistic, by some members of the S^3-group. However, they provided the foundation for spirited discussions and exchanges of ideas pertinent to the fundamental processes involved in small-scale sediment dynamics whether the assumed level of ability to model turbulent flows is available or not.

It was generally agreed upon that a dynamically based model of small-scale sediment transport mechanics should consider, at a level of complexity commensurate with our fundamental knowledge of, and ability to quantify, the movement of individual sediment grains.

The prerequisite for achieving this is the establishment of *equations of motion for sediment grains in a turbulent flow*, which should account for the following fundamental processes.

Lift and Drag on Sediment Grains

If we start from a physical condition corresponding to "initiation of motion" the detailed structure of the turbulent flow over a sediment bed (including velocity and pressure fluctuations) provides part of the hydrodynamic forcing (lift and drag) for individual sediment grains.

Role of Flow within the Bed

However, in the nearshore environment (in particular within the surf and swash zones) strong gradients in the near-bottom pressure will induce a flow within the porous bed, which will provide an additional hydrodynamic forcing for grain motion.

Grain-Grain Interaction

In addition to the submerged weight of individual sediment grains the contact forces from surrounding grains will provide resistance against movement. Once in motion--whether in the form of individual grains being ejected from the bed or as bulk movement of the bottom sediments--grain-grain interactions continue, e.g., through collision with other moving grains or through impact with bottom sediments upon return to the bed.

Sediment-Fluid Interaction

For the problem of "initiation of motion" the bottom sediments are essentially immobile, i.e., corresponding to the "concrete beach" for which the turbulent flow is presumed known. However, once in motion the sediment grains act on and affect the characteristics of the turbulent flow, i.e., the "concrete beach" assumption for the hydrodynamics breaks down. Some of the fundamental questions to be answered are: What is the effect of a moving granular bed on the turbulent flow above? What is the effect of the presence of sediment grains on the characteristics of a turbulent flow? What is the nature of bed-response (ripple formation) and its effect on the turbulent flow above the bed?

SHORT-TERM GOALS

It was generally agreed that simplified versions of the equations of motion of individual sediment grains were available and should be used as the basis for a rational formulation of sediment transport mechanics in the nearshore environment. Based on simplifying hypotheses and parameterizations of the physical processes described in the long-term goals important questions such as the response time of sediment grains to fluid forces, which would set the upper limit of the frequency resolution required by turbulence modelers, could be answered and preliminary dynamically based models for sediment transport could be established.

Theoretical developments along this line should go hand in hand with laboratory and field experiments aimed at testing hypotheses and parameterizations associated with the fundamental processes included in the theoretical models.

Particularly pertinent problems to be addressed immediately were identified as indicated below progressing seaward from the shoreline and with "waves" being interpreted an "spectral" (not monochromatic) waves.

- Dynamics of sediment transport in the *swash zone* with particular attention to the role of flow induced within the bed. (Is swash zone transport important? What is the appropriate shoreline boundary condition for shoreline evolution models?)

- Sediment transport mechanics in the *surf zone.* (Is "bedload" or "suspended load" the mode of transport? If "suspended load" is important what are the turbulence characteristics in the surf zone, e.g., is the near-bottom turbulence dominated by wave breaking or by the turbulent near-bottom shear flow? What is the appropriate value of the friction factor used in the prediction of longshore currents? Is the bulk motion of bottom sediments, i.e., granular flow induced by shear and/or flow within the bed, important?

- Sediment-fluid interaction in the *offshore zone.* (What are the geometry and hydrodynamic characteristics of wave-generated bedforms? What is the character of wave-current interaction (friction factors) over a rippled bed? How should sediment transport mechanics for waves and currents over a rippled bed be quantified?)